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RESEARCH ARTICLE

Climate Change in the Peruvian Andes: A Case Study on Small-Scale Farmers' Vulnerability in the Quillcay River Basin

Anna Heikkinen

Previous studies have shown that climatic changes in the Peruvian Andes pose a threat to lowland communities, mainly through changes in hydrology. This study uses a case study approach and a mixed qualitative-quantitative method to examine the vulnerability of small-scale farmers in the Quillcay River basin to variations in precipitation and enhanced glacier retreat. The findings of the study show partly contradicting results. On one hand, interpretation of semi-structured interviews suggests a strong relation between climate proxies and increased vulnerability of the smallholders. On the other hand, in the quantitative analysis enhanced glacier retreat seemed to have augmented vulnerability solely to some extent whereas precipitation did not show significant impact. The assessment of the socioeconomic dimension revealed that larger market forces, weak political entitlement and lack of social and economic capital fundamentally increased smallholders' vulnerability. It is, therefore, suggested that a complex cluster of economic, political and social factors are the root causes of small-scale farmers' vulnerability in the case study region whereas climate-related changes merely act as multiplying factors.

Keywords: Climate Change; Hydrology; Peru; Small-scale Farming; Resilience; Vulnerability

Introduction

Peru, hosting the largest share of the world's tropical glaciers, has been ranked as one of the countries in the world most vulnerable to the impact of climate change (UNEP 2013). Consequences of global warming can already be observed, such as accelerated melting of glaciers and anomalies in precipitation patterns, especially in the Andean region. This poses a serious threat for the Andean societies since glacier meltwater and precipitation provide essential sources of water for the lowland residents, agriculture and industry.

Throughout the Andean mountain range, *cordillera*, rural populations already have restricted access to potable and irrigation water. Poor highland communities have less capacity to respond to the increasing water scarcity due to weak infrastructure, low income, strong reliance on agriculture and limited opportunities for alternative livelihoods. Therefore, it is projected that rural populations in the Andes will be particularly vulnerable to the shortages of water enhanced by climate change (Painter 2007: 9, 11).

Besides climatic causes, vulnerability to climatic hazards is strongly linked to political, social and economic reasons as well as geographical location of a population (Ojha et al. 2015: 4; Turner et al. 2003a: 8085). A vulnerability study from Mexico acts as an illustrative example by showing that local farmers' vulnerability to environmental hazards was a consequence of multiple factors such as access to biophysical and social resources, policies and land management (Turner et al. 2003a: 8083). What defines vulnerability of a certain group is generally its capacity to adapt (Altieri & Nicholls 2013: 10). Evaluations of socio-ecological vulnerability in the Arctic for instance found that local people's ability to adapt to the outside stresses, such as changes in the global markets and environmental pollution, was closely bound to government decisions. Therefore, the authors argue that in order to design adequate adaptation practices, it is essential to include perceptions of local people in the vulnerability assessments (Turner et al. 2003a: 8085).

A large amount of studies has been conducted on climate change and glacier retreat in the Andean region from the natural science standpoint, demonstrating clear evidence of the biophysical impact of climate change (Perez et al. 2010: 11; Vuille et al. 2008: 94; Drenkahn et al. 2015: 727). However, assessments of vulnerability of local people to climatic changes, particularly in rural highlands of the Andes, remain few (Painter 2007: 2). This also becomes important regarding the long history of highland populations being in a marginalized position in Peruvian society compared to coastal, urban residents (Carey 2005: 127).

Against this background, this study seeks to further advance understanding of climate-related vulnerability of

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rural populations in the context of Huaraz, Peru. A case of the Quillcay River basin was used to measure the vulnerability of local smallholders to climatic and hydrological changes through investigating relations between glacier recession, changes in precipitation and socioeconomic factors. This was implemented using a mixed method, intertwining smallholders' perceptions with statistics. Besides aiming to contribute to the existing climate vulnerability literature in the Andes using a different perspective and less conventional method, the findings of this paper aim to provide guidelines for local policymakers to improve planning of all-encompassing adaptation strategies.

After briefly reviewing previous literature on implications of climatic changes in the Andes this paper introduces the case study site followed by explanations of the theoretical vulnerability approach, methodology and data used in the study. Towards the end of the paper, both qualitative and quantitative results of the study are presented, annexed and discussed. In the final section, the key conclusions are drawn and recommendations for future vulnerability evaluations in the region are provided.

Climate Change and Its Implications for the Andean Residents

Climate change is one of the most fundamental concerns of our era. Robust evidence shows that the global mean temperature has significantly risen during the last 100 years (IPCC 2013: 121, 127). Enhanced rise of global temperature has already caused variability in climate patterns in certain parts of the world. Furthermore, extreme weather events such as floods, heat waves and droughts have become more frequent and intense (IPCC 2014: 11077). Mountain regions are especially sensitive to changes in climate. Temperature in mountain glaciers is for instance often close to the 0°C threshold and therefore even tiny changes in temperature or precipitation result in melting of the snow-pack (Benitson 2003: 6, 10).

The tropical Andes, out of which 71% are found in Peru, form almost entirely the world's tropical glaciers. Specific characteristics of the tropical Andes make them particularly vulnerable to climatic variations. Previous studies have already demonstrated that glacier recession in the tropical Andes has accelerated during the last decades due to raised global temperature (Painter 2007: 1; Vuille et al. 2008: 79; Bradley et al. 2006: 1755). Changes in climate regimes have a crucial impact on the natural hydrological cycle of the glaciers. The variations in the temperature disturb the glacier-based river runoff causing deficits of water or flooding, endangering water distribution of lowland socioeconomic systems (Benitson 2003: 7, 14).

The region of the Peruvian Andes is characterized by seasonal precipitation. The annual hydrological cycle is divided into a rainy season from October to April and a dry season from May to September (Gurgiser et al. 2015: 1864; Mark et al. 2010: 795). However, recent monitoring of the Andes has revealed abnormal changes in precipitation: the observations indicate that in recent decades there has been a slight decrease in total precipitation and considerably higher variation between torrential rain and the absence of rain (Sanabria et al. 2014: 1534; Haylock et al. 2006: 1510). Although the total rainfall in the region has not yet changed significantly, strong year-to-year variability in precipitation has been identified particularly in the Cordillera Blanca of Peru (Gurgiser et al. 2015: 1884).

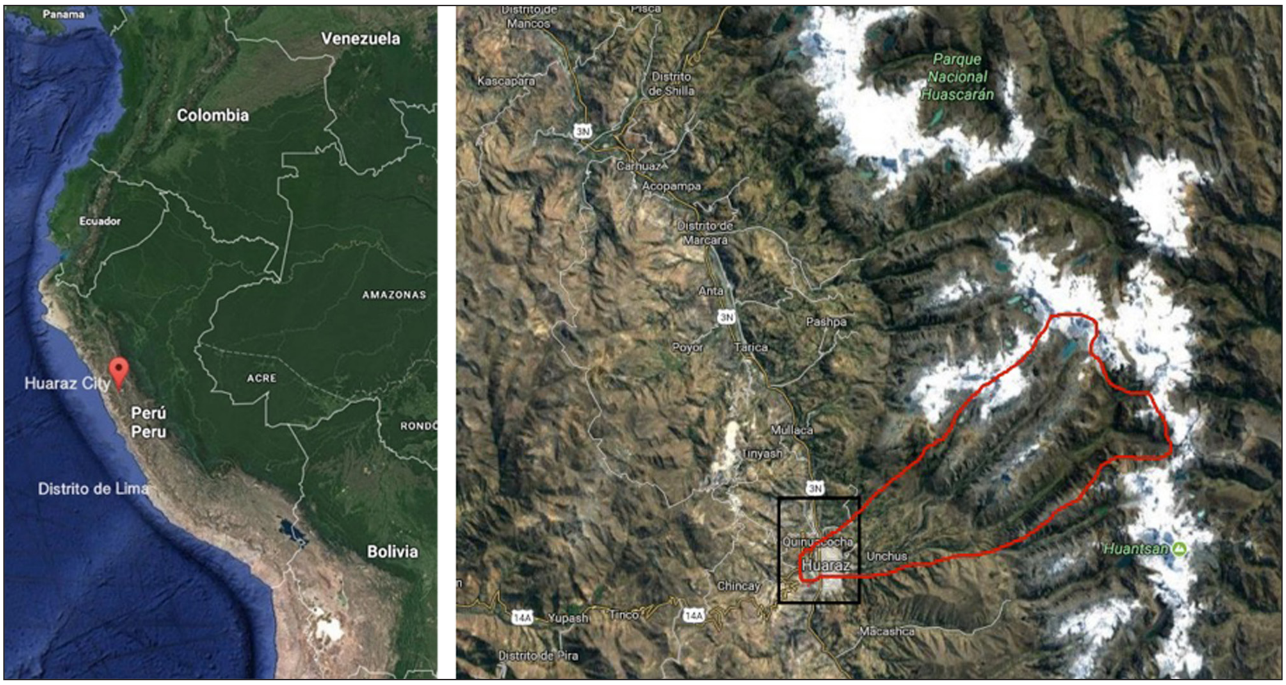
Agriculture has traditionally been the most important livelihood in the Peruvian Andes. It is estimated that six million people living in the Andean highlands still rely predominantly on small-scale farming as their main subsistence (Painter 2007: 10; Sanabria et al. 2014: 1533). Small-scale production in the Andes is mainly rain-fed and during the dry season water for irrigation is almost solely received from glacier melt-water (Sanabria et al. 2014: 1533; Mark et al. 2010: 796; Bradley et al. 2006: 1756). However, studies have found that rain-fed agriculture in the Peruvian Andes has been deteriorating during the recent decades due to decreased rain during the dry period, an earlier wet season and unpredictable precipitation (Gurgiser et al. 2015: 1884). Destroyed yields consequently subject smallholders to remarkable economic losses illustrating the threat of climatic changes to highland residents in the Peruvian Andes. Previous studies have hence urged further investigation of the phenomenon (Mark et al. 2010: 803).

In addition to climatic factors, studies suggest that under the neo-liberal economic scheme during the last decades social inequality and deprivation have increased especially among the poor highland farmers (Crabtree 2003: 130, 137, 140, 150). In the 1990s, as in many other Latin American countries, the political economy in Peru went through a profound transformation from state regulation towards a liberal economy (Crabtree 2003: 129). The primary aim of the shift was to enhance export-oriented growth. The new neo-liberal reform thereby led to favoring large-scale agricultural units on the coast due to their higher productivity, better access to urban centers and export markets. Small-scale producers in the highlands with smaller yields and more challenging sowing circumstances were left with little importance, albeit, they have historically had an important role in producing traditional Peruvian crops.

The Quillcay River Basin

The case study was conducted in small communities (*centros poblados*) along the Quillcay River basin in the community of Huaraz, belonging to the Department of Ancash, Peru (**Map 1** and **Map 2**). The field study region was chosen due to previously reported threats related to accelerated glacier recession, changes in climate and small-scale farming being the dominant livelihood. The Quillcay River basin pertains to the Cordillera Blanca (Mark et al. 2010: 797; Colonia & Torres 2013: 5) representing the largest glacier cluster of Peru (Mark et al. 2005: 2266; Portocarrero 1995: 218).

The Quillcay River basin consists of two main micro basins, the Auqui River and the Paría River. The micro rivers unite at downstream of the basin in the city of Huaraz and form the Quillcay River that ultimately falls into the Santa River (Colonia & Torres 2013: 5). The Auqui River and the Paría River form the main water supply for the district of Huaraz. Glacier melt-water provides the major source of water, particularly in the upper stream of



Map 1 and **Map 2:** Location of Huaraz. The Quillcay River basin is indicated with the red line. Source: Edited by the author, based on Google Maps 2017.

the basin. Precipitation contributes to the river watershed during the rainy season (October–April) along the whole stream (Rivas, Cuellar & McKinney 2014: 5; Gurgiser et al. 2015: 1864–65).

There are approximately 50,000 inhabitants living in the Quillcay River basin, amounting to nearly half of the total population of the municipality of Huaraz (MINAGRI, 2015). Small-scale farming is still the most prevalent subsistence in the area: 80% of the population receives their main income from small-scale agriculture and livestock production (Mark et al. 2010: 796). Most of the fields are still rain-fed (70%) and rely on precipitation for irrigation. Some farmers use irrigation systems (30%) fed by the glacier melt-water (Castro 2016). Smallholders of the region are, therefore, highly vulnerable to the disruptions in precipitation or glacier originated river discharge (Mark et al. 2010: 795–796).

Semi-structured interviews were conducted with 16 small-scale farmers living in the Quillcay River basin (11 men, 5 women). Smallholders representing older generations (aged 40 and above) were chosen for the sample in order to capture a longer historical trajectory of climatic changes in the region. It was also considered important to include perceptions of both genders. Furthermore, eight key informants from distinct agriculture, climate, glacier and water institutions were interviewed. Most of the smallholder respondents were fluent in Spanish, but some of them only spoke the indigenous Andean language, Kichwa. Therefore, a local English language student who knew Spanish, Kicwha and English participated in the fieldwork as an interpreter. Ethical guidelines of social research were strictly followed in this study. Every informant was given an informant consent form stating the aim of the study and guaranteeing confidentiality. The anonymity of the smallholder interviewees has been ascertained by referring to them as "informants". The key informants from the institutions have given permission to publish statements using their names.

Theoretical Approaches: Vulnerability and Resilience

Analytical frameworks of vulnerability are advantageous tools in research on socio-ecological systems' exposure to climate hazards, weak resilience and marginal social conditions (Adger 2006: 268). In this study, vulnerability framework of the Research and Assessment Systems for Sustainability Program by Turner et al. (2003b) was applied in the analysis of interview material. Here, first short introductions are provided on the concepts of vulnerability and resilience, followed by explanation of the vulnerability framework and how it was utilized for the analysis.

Vulnerability

The legitimate authority on climate change, Intergovernmental Panel on Climate Change (IPCC 2007: 883), defines climate-related vulnerability as 'the degree to which a system is susceptible to, and unable to cope with effects of *climate change*, including *climate variability* and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its *sensitivity,* and its adaptive capacity'.

Vulnerability as a state, hence, refers to a situation in which a socio-ecological system[1] is exposed to external stresses and has low adaptive capacity. External stresses imply adverse human or environmental influence outside the system, such as climatic hazards or unequal distribution of resources in the society (Adger 2006: 270; IPCC 2014: 1052). Vulnerability is regarded as constituting the following elements: exposure and sensitivity to hazards or stresses, resilience and capacity to adapt. *Exposure* refers to the magnitude and duration that the system is subjected to environmental or human-influenced stresses or perturbations (Adger 2006: 270; Gallopín 2006: 294, 296). *Sensitivity* on the other hand can be defined as the degree of external stresses the system encounters and the system's potential to respond to the exposure of human or environmentally originated forces (Adger 2006: 270; Luers 2005: 215). *Adaptive capacity* refers to the extent the system can adjust to the harm caused by stresses and how it can cope with the impacts or even improve its state (IPCC 2007: 896; Gallopín 2006: 300). Lastly, *resilience* applies to the amount of stresses and perturbations a system can endure and still maintain a relatively stable state after the exposure to disturbances (IPCC 2007: 880; Turner et al. 2003b: 8075).

Several interpretations of vulnerability exist and are in use depending on the orientation of the study. In this paper, the emphasis is to assess the vulnerability of smallholders to climatic stresses and therefore the social vulnerability approach was adopted. In the social vulnerability stance, the focus of the analysis is in present vulnerability, prior to external stresses, and finding strategies to strengthen adaptive capacity in advance of future climate stresses. Capacity to reduce vulnerability is seen as an outcome of multiple environmental, climatic, political and social dimensions.

Resilience

The theoretical approach of resilience is often favored in the research exploring socio-ecological systems exposure to climate stresses and their adaptive capacity to undesirable changes (Nelson, Adger & Brown 2007: 395). The concepts of vulnerability and resilience share numerous common core interests as both research traditions aim to explain human-environment interactions, especially the response and adaptive capacity of human and environmental systems to the external shocks (Adger 2006: 269).

The contemporary resilience theorists conceptualize resilience as 'the capacity of systems, communities, households or individuals to prevent, mitigate or cope with risks, and recover from shocks' and suggest that 'a system is resilient when it is less vulnerable to shocks across time, and can recover from them'. In order to strengthen resilience of a system, its exposure to biophysical, economic and social risks should be tackled and thus decrease vulnerability and strengthen its adaptive capacity (Gitz & Meybeck 2012: 29–30; IPCC 2007: 880).

Vulnerability Framework

The vulnerability framework of the Research and Assessment System of Sustainability program by Turner et al. (2003b) was chosen for this study due to its capacity to capture myriad linkages affecting vulnerability (**Figure 1**). The framework allows to broadly explore the interactions of coupled human-environment systems at three levels (world, region and place), how these systems respond to hazards and to what extent they are vulnerable to the outside stresses. In the analysis of the framework questions such as who are vulnerable to the environmental changes, what are the consequences of the changes and how the vulnerability caused by the changes can be reduced are addressed (Turner et al. 2003b: 8074).

The framework was originally designed to serve vulnerability evaluations within the research of sustainability and global environmental change. It therefore has an

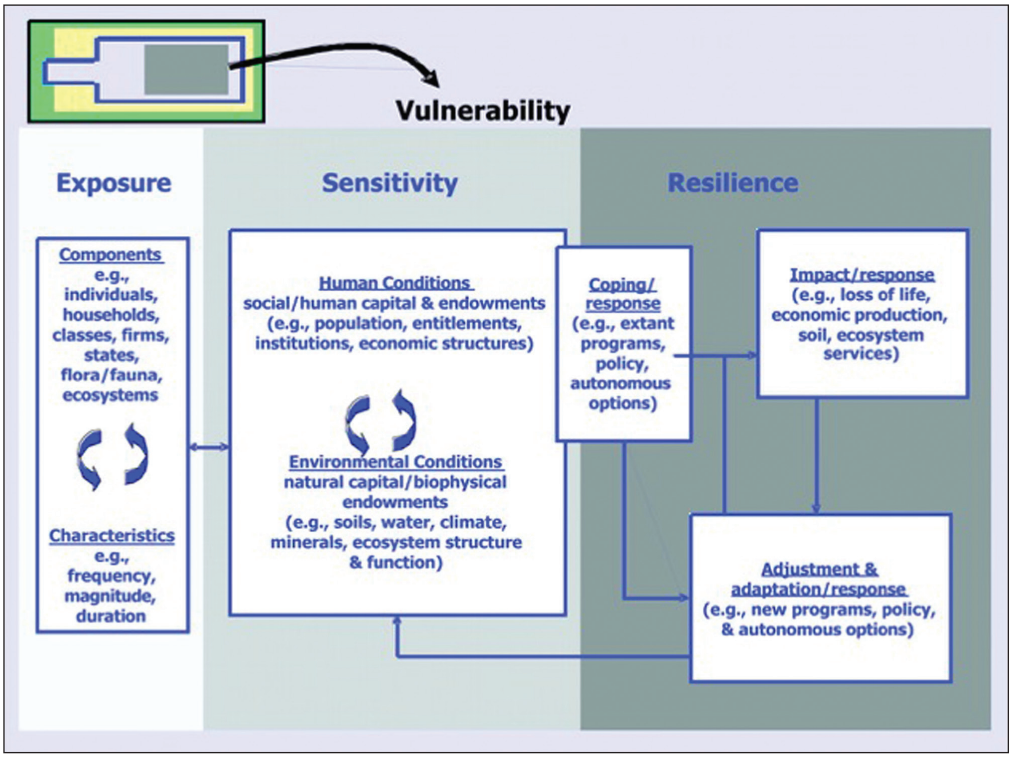


Figure 1: Place-dimension of vulnerability framework of the Research and Assessment System for Sustainability Program by Turner et al. (2003b) applied in this study.

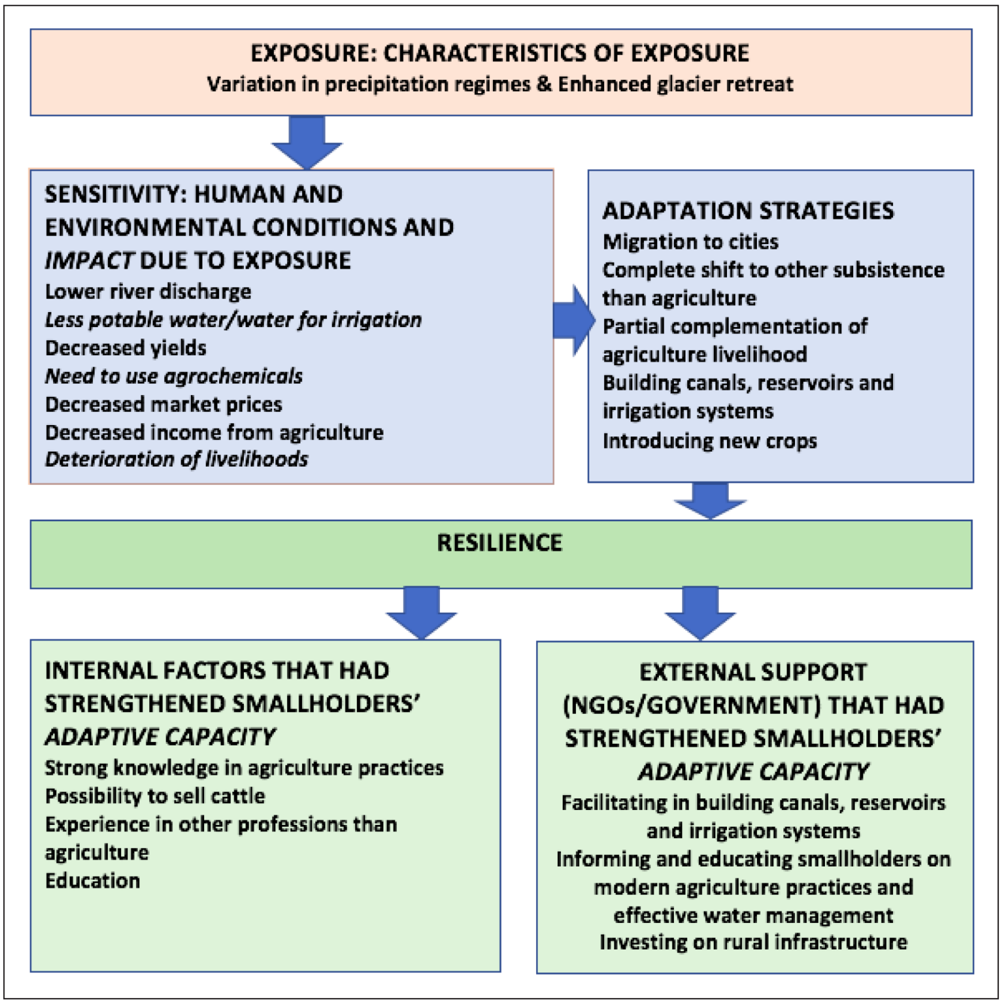


Figure 2: Factors that had affected smallholders' vulnerability in the Quillcay River basin, adaptation strategies in use and factors strengthening adaptive capacity to enhance resilience. Source: Author, based on vulnerability framework of Turner et al. (2003b).

ambitious goal to include myriad connections affecting vulnerability that have been lacking from previous vulnerability frameworks. However, the drawback of fitting in so many variables in one framework is that it makes the analysis somewhat complex. The authors therefore suggest that each study should adjust the framework to the context and dimension of the research (Turner et al. 2003b: 8076).

Since a case study is in question, the focus of the analysis was majorly on the *place* dimension of the framework. Vulnerability aspect was examined through *sensitivity* of small-scale farmers to the stresses caused by climatic and hydrological changes in the Quillcay River basin. This was implemented firstly by assessing the magnitude of the climatic and hydrological stresses the smallholders in the study site currently encounter. Secondly, by evaluating the impacts on well-being and livelihoods of the farmers due to *exposure* of stresses and lastly, by identifying amount of *resilience*, i.e. what is the *adaptation capacity* of the small-scale farmers to climatic and hydrological changes, which factors have facilitated successful adaption and what are the elements that should be addressed to strengthen their resilience.

The process was guided by a common qualitative method – thematic analysis. The interview material was first coded and secondly, guided by the codes, relevant categories were identified using the vulnerability framework and new themes that arose from the interviews. Lastly, the frequency of the codes appearing under each theme was examined. A summary of the process is illustrated in **Figure 2**. The principal themes are indicated with capital letters and the codes are found below each theme.

Quantitative Measurement of Vulnerability

Vulnerability can also be assessed by more tangible measures of well-being, such as mortality, income, wealth and access to education (Adger 2006: 276). In this study, harvested area, farm gate prices and growth rate of rural population were applied to quantify the adverse changes in the livelihoods and well-being of the smallholders in the study area. Moreover, glacier mass-balance and precipitation were used to indicate the climatic and hydrological changes. In the Quillcay River basin most water in the rivers originates from the lakes formed of glacier melt-water (Rivas, Cuellar & McKinney 2014: 2). This represents the strong interaction between the glaciers and the rivers in the basin. Variability in glacier mass-balance is therefore used as an indicator for the changes in volume of the river discharge.

The most cultivated crops in the Department of Ancash are corn, potato and wheat (Castro 2016). The harvested areas of corn, potato and wheat were, therefore, chosen to measure changes in the agricultural livelihood activity. Farm gate prices of the three crops were used as indicators for changes in income received from agriculture.

Change in growth rate of rural population in the Department of Ancash was deployed to capture the relation between climatic and hydrological changes and changes in the smallholders' social well-being. Rural regions often suffer from weak economic development compared to urban areas; employment possibilities are narrower and infrastructure less developed, being a common reason for rural residents to migrate to the cities in seeking to raise quality of life. (Agesa & Sunwoong 2001: 61–62)

In the quantitative analysis, Pearson's correlation was used to explore whether correlation between climatic proxies (mass-balance and precipitation) and socioeconomic variables (harvested area, farm gate prices and growth rate of rural population) exists. In order to discover to what extent climatic factors explain vulnerability of the smallholders, ordinary linear regression method was applied.

Data

Lack of data or incomplete historical data series have previously complicated research in the Andean region (Drenkhan et al. 2015: 276; Salzman et al. 2013: 104). These challenges were not avoided in this study: some data from the study region existed solely from recent years or had not been systematically monitored. Therefore, some data adjustments and assumptions had to be made.

Monitoring of the glaciers located in the proximity of the Quillcay River basin, such as Shallap and Palcaraju, has only begun recently and data on most of the glaciers does not exist before the beginning of the 21st century. Therefore, in this study mass-balance data from the most surveyed glacier of the Cordillera Blanca, glacier Yanamarey, was used. Glacier Yanamarey is situated in the province of Recuay (Rosario & Cruz 2014: 45), approximately 70 kilometers from the Quillcay River basin and mass-balance data exists from 1948.

In this paper, it is presumed that due to the glacier Yanamarey's close geographical location to the study area, the climatic conditions are relatively equal in the two regions and that mass-balance changes of glacier Yanamarey are comparable to the glaciers located in the hinterland of the Quillcay River basin. The data used for the analysis represents the annual retreat or accumulation of the glacier Yanamarey (Rosario & Cruz 2014: 49).

Data on precipitation in the region of Huaraz have been collected since 1972 until present however, data was missing between 2000–2002 and in 2012. To overcome the missing data from these years, linear interpolation method[2] was applied. Both data series, on glacier mass-balance changes and precipitation were obtained from the databases of the Unit of Glaciology and Hydrological Resources (UGRH) of Huaraz.

Since agricultural data from the region of Huaraz was only available since 1997, the data from the whole Department of Ancash was used. This study assumes that the trends in harvested area and farm gate prices of Department of Ancash correspond to the trends of the study area. The assumption was based on the pilot analysis performed with data on harvested area and farm gate prices that was available from Huaraz from 1997 to 2013. MINAGRI maintains encompassing agricultural databases from the Department of Ancash and data for the harvested area of potato, corn and wheat exist from 1950s. Information on farm gate prices for all the crops has been collected since 1963.

The changes in rural population growth from the Department of Ancash exists from the years 1940, 1961, 1972, 1981, 1993 and 2007 in the registers of The Peruvian National Institute of Statistics and Informatics (INEI). Missing data had to be interpolated in a manner that the arithmetic mean of the last existing values was calculated and the achieved average was placed as an estimate between these years.

As shown above, data from the Andean region exists but it is often inadequate. A time span, from which the most cohesive data sequences from all the variables could be obtained was attempted to identify to provide an encompassing analysis. Eventually, after evaluation of the data, the period from 1972 until 2015 was chosen for this study.

Smallholders' Vulnerability to Climatic Changes in the Quillcay River Basin

During the interviews, the smallholders discussed diverse climatic changes that they had observed in the Quillcay River basin during the last decades. However, glacier retreat and lack of rain were the most mentioned changes. Almost all the interviewees told that they had noticed that the rainy period has become shorter and when it rains the rain is torrential and not continuous as it used to be. The smallholders also reported that because of these changes in precipitation, yields were sometimes damaged or lost.

> Before when it was raining, the rain was calm. But now when the rain arrives, it is torrential… and it washes away all the soils. (Informant no.2)

Glacier retreat was a concern for many informants from a cultural perspective since the white glacier peaks have traditionally been a landscape trademark of Huaraz. However, the smallholders were also feeling uncertain how deglaciation will affect water in the rivers and consequently, available irrigation water. The informants reported that there was less water now in the rivers than before and they associated the decline of water with the shortened rainy period and melting of glaciers. Due to scarcer water supply, the farmers told that their access to potable and irrigation water was nowadays more limited. The smallholders were also concerned that their yields had in recent years declined or been damaged which they believed is connected to the disappearing of the glaciers.

> For example, we have cultivated potatoes…and now there is almost nothing anymore…everything is lost…there hasn't been production. Why? Because

> of the rain, it hasn't rained! With what else could we irrigate? (Informant no.10)

The smallholders also perceived that they now gain less income from farming. Despite changes in precipitation and deglaciation, the reason for decreased income from agriculture was said to be a growing need to use fertilizers. The farmers told that fertilizers are costly and therefore, their use lowers the net income received from agricultural products. It was also argued that the market price of agricultural products had fallen considerably during the last decades. Declined market prices had led to a situation where the smallholders did not find it worthwhile to make additional investments in agrochemicals and then descend to the city to sell the products since the prices did not cover their labor input and the increased production costs.

> …the market price is very low now. And that is not convenient for us at all. – we are paying for the fertilizers and pesticides and it [agriculture] doesn't pay back anymore. Therefore, the agriculture production has lowered…who would sow if it doesn't pay back? And many people have left the countryside to work at the construction…to find other sources of income… (Informant no.7)

Many smallholders were attempting to adapt to the changed circumstances; some had moved to the cities or obtained additional sources of income to compensate for the lost income from agriculture. Additionally, some farmers had constructed irrigation systems, begun to use fertilizers or attempted to cultivate new crops that suit better the changed climatic conditions. All the adaptation strategies mentioned, however, required education, additional professional skills or sufficient economic assets that all the interviewees had not access to.

> Yes, I have thought about it [moving to Huaraz] but when you don't have that economic situation…you just can't. (Informant no.15)

External support was found to have a key impact on strengthening adaptive capacity of the smallholders, especially of those who otherwise had low financial or social capacity. The municipality of Huaraz was reported to be the major actor constructing new canals and reservoirs in the region as well as providing material aid for the rural residents. However, it remained unclear how the projects were distributed since some of the farmers told that they never received any kind of help from the municipality. Local NGOs were said to have helped to construct reservoirs for potable water in some villages of the study area. According to the interviewees there is a growing need for projects to construct irrigation systems due to the shortening rainy period in order to avoid shortages of water. Overall, the small-scale farmers who had received materials or financial aid from the municipality or local NGOs to construct canals and reservoirs, said that they had enough potable and irrigation water while those who had not received any kind of help claimed that they were suffering from lack of water and declining yields.

Additionally, some smallholders initiated a discussion that they feel "forgotten" compared to urban residents. The interviews were conducted under the presidential election campaigns in 2016 and some smallholders told that currently the politicians come to visit them with many promises. However, their experience from previous political campaigns was that these promises were later never fulfilled.

> How could I say…now they are looking for votes and these people arrive with their hats and traditional costumes. They want to show that they are as we are, rural [indigenous] people. But when they enter [to parliament]…they don't listen to us anymore." (Informant no.14)

The authorities that were interviewed for this study agreed that changes in precipitation and glacier recession have already affected the highland watersheds and consequently pose challenges for small-scale farming in the region. However, some of them mentioned that it was sometimes difficult to begin developing projects in the rural communities because local people do not always want to cooperate with the authorities. The authority informants also raised additional factors, such as low education of rural residents, weak knowledge in efficient use of water, skills in modern agriculture practices and lack of political entitlement in rural areas. They considered that these are the major reasons behind the socioeconomic problems in the rural highland regions and that interference of climatic changes only makes the situation worse. In addition, the authorities emphasized that the key in building efficient adaptation strategies would be promoting education, providing novel research on agriculture and stronger governmental involvement.

> The solutions [to prevent social dilemmas in rural areas due to changes in climate and hydrology] would go through educating both protagonists: specialists and farmers in order to improve the cultivating methods. And as well, we would need good state policies that would be capable and adequate to resolve these great problems with social sensibility and sustainable methods. For great problems, we need great solutions, and this would only be possible through good policies and good government. With the articulation of these components, these problems could be solved. And in Peru, the current situation is not quite like that. (Sántillan 2016)

Statistical Relation of Climate Change and Smallholder's Vulnerability

Pearson's correlation and ordinary linear regression analysis were conducted to test the strength and nature between climatic and socioeconomic variables and to be able to compare the statistical results with the qualitative findings. The results from Pearson's correlation analysis show relatively strong correlations were found between glacier retreat and harvest of corn (0.495), harvest of potato (0.466) and harvest of wheat (0.524). The harvested area for all three crops correlated rather weakly with precipitation: corn (0.077), potato (0.042) and wheat (0.205).

Weak positive correlations were found between the farm gate prices and the climate proxies. The strongest correlations were found between the farm gate price of corn and precipitation (0.210) and the farm gate price of potato and precipitation (0.280). The correlation between the farm gate price of potato and glacier retreat was weak and negative (–0.012). Growth rate of the rural population showed negative correlation with both precipitation (–0.164) and glacier retreat (–0.257).

The results from Pearson's correlation thus give an indication that accelerated glacier retreat has had an impact on the decline of the harvested land. Precipitation, however, cannot be proven as a unique cause of decline in the harvested area. Detailed results of Pearson's correlation are illustrated in **Table 1**.

Ordinary linear regression analysis showed a modest coefficient of determination values (r^2) between all the independent variables (glacier retreat and precipitation) and on the other hand the dependent variables (harvested area of corn, potato and wheat, farm gate prices of corn, potato and wheat and growth rate of rural population). Glacier retreat was found to explain well the changes in the harvested areas, especially the decline in the harvested land of wheat ($p = 0.000$). On the other hand, precipitation was not found to be significant in explaining changes in the harvested areas. Modest significance was discovered, however, in explaining changes in harvested area of wheat ($p = 0.217$).

Farm gate prices of corn, potato and wheat all received low r^2-values in relation to precipitation and retreat. The p-values for the farm gate prices of the three crops were found high for glacier retreat and low for precipitation, indicating that glacier recession is not significant in explaining the changes in the prices. In contrast, precipitation was found to be significant to some extent to explain growth in farm gate prices. The price of potato ($p = 0.177$) showed the highest significance in relation to precipitation. Lastly, according to the results, precipitation and glacier retreat explain only weakly the changes in growth rate of rural population. Glacier retreat, however, was discovered to have a higher level of significance ($p = 0.108$) than precipitation ($p = 0.342$). Results of linear regression analysis are illustrated in **Table 2**.

Summing up Perceptions of the Informants and Statistics

Findings of the current study suggest that there are some discrepancies between how small-scale farmers perceive their vulnerability to climatic changes, how the interviewed authorities view the situation and what statistical evidence demonstrates. In line with the results of interview data, quantitative analysis confirmed that glacier retreat has influenced agricultural practices in terms of decline in harvested area of corn, potato and wheat. Parallel results have also been achieved in the studies in other parts of Cordillera Blanca (Mark et al. 2010: 803).

However, monitored data on precipitation did not show significant changes in long-term precipitation patterns in the study region but as previous studies from other parts of the Peruvian Andes, it revealed high inter-annual volatility in precipitation during recent years. The smallholders' perceptions on shortened rainy period and variability in precipitation, seem to respond to the statistics. However, no strong effect of decreased precipitation on the decline in the harvested areas was found. Therefore, it is suggested that it is irregular rain events that pose challenges for small-scale agriculture in the study site rather than lack of precipitation.

Despite the informants' arguments that changes in climate and hydrology have affected income they receive from agriculture, the statistical measurements did not

Table 1: Correlations between climate proxies and socioeconomic factors. Upper value indicates the correlation (r) and value in parenthesis one-tailed significance level (p). Source: Author, based on the data obtained from MINAGRI, INEI and ANA.

	Harvest Corn	Harvest Potato	Harvest Wheat	Price Corn	Price Potato	Price Wheat	Rural Population
Retreat	0.495	0.466	0.524	0.011	–0.012	0.028	–0.257
	(0.000)	(0.001)	(0.000)	(0.473)	(0.496)	(0.428)	(0.046)
Precipitation	0.077	0.042	0.205	0.210	0.208	0.185	–0.164
	(0.310)	(0.394)	(0.091)	(0.086)	(0.088)	(0.114)	(0.144)

Table 2: Results of linear regressions analysis. Coefficient of determination (r^2) presented above and statistical significance (p) below in parenthesis. Source: Author, based on the data obtained from MINAGRI, INEI and ANA.

	Harvest Corn	Harvest Potato	Harvest Wheat	Price Corn	Price Potato	Price Wheat	Rural Population
Retreat	0.246	0.217	0.301	0.044	0.044	0.034	0.087
	(0.001)	(0.002)	(0.000)	(0.969)	(0.852)	(0.931)	(0.108)
Precipitation	0.246	0.217	0.301	0.044	0.044	0.034	0.087
	(0.782)	(0.972)	(0.217)	(0.178)	(0.177)	(0.238)	(0.342)

endorse these statements. Firstly, after correcting the impact of inflation,[3] the data series showed an increase in farm gate prices of all three crops, considerably since 1990s. Data on farm gate prices thus suggest that the income from agriculture should have increased. Secondly, according to the regression analysis precipitation explains only partly growth in the farm gate prices whereas glacier retreat had almost no significance in explaining changes in the prices.

The small-scale farmers considered that change in climatic conditions was a major reason why people had begun to migrate from highlands to cities. In the statistical analysis, however, the climatic variables explained the negative trend in growth rate of rural population only to a certain degree. Furthermore, during the interviews both smallholder and authority informants also mentioned additional reasons for migration such as unfavorable market set-up for smallholders due to favoring large-scale agriculture production, families abandoning farming for more stable income and the young generation moving away to seek better education and work opportunities. Hence, it is suggested that climatic factors seem merely add to myriad causes enhancing emigration.

There are several reasons why partly reverse results were obtained from qualitative and quantitative analyses. Firstly, when evaluating qualitative data based on people's memories and views, the researcher should be aware of the fallibility of the human mind. For example, exceptional weather of recent years can lead to unintentional exaggeration of climate change although the phenomenon might just as well be part of a natural annual climatic variation. Moreover, awareness of participating in a study measuring impacts of climate change might have led the participants to consider climate to be the culprit for all the socioeconomic challenges they encounter.

Secondly, as has become explicit in this study, vulnerability of smallholders in the rural highlands consists of diverse factors. Therefore, it might be that a more complex statistical index should be created and used in quantitative climate vulnerability assessment in order to capture the diverse linkages.

Thirdly, due to limitations of this study, numerous variables that may have had an impact on the vulnerability of the smallholders had to be excluded. The authorities for instance emphasized the influence of larger political and economic structures on the contemporary socioeconomic struggles in the rural highland areas. In line with smallholders' feelings of being excluded from the society, the statements of authorities suggest that the rural areas are currently omitted in terms of adequate political engagement. Furthermore, although use of mixed methods allows more extensive scrutiny of a research problem it also poses a challenge in terms of matching the quantitative and qualitative data samples. Future studies are therefore encouraged to explore ways of how the complex impact of diverse social, economic, political and environmental factors could be coherently embedded in both quantitative and qualitative evaluations of vulnerability of marginalized populations in the Andes and other regions where equivalent problems are a concern.

Conclusions

This paper has examined to what extent climatic and hydrological changes have adversely affected vulnerability of smallholders in the Quillcay River basin in the Peruvian Andes using mixed methods, intertwining perceptions of local people, authorities and statistics. The findings of the semi-structured interviews demonstrate that smallholders are concerned for the contemporary changes in local climate and environment, greatly enhanced glacier retreat and lack of rain. In the qualitative analysis, exposure to the changes was found to complicate small-scale farmers' access to potable and irrigation water, damaging the yields and thus deteriorating their livelihoods and diminishing their income. The statistical analysis endorsed the negative impact of glacier recession on agricultural livelihoods; however, the statistics did not verify the considerable influence of precipitation. No significant correlation was found either between climate variables and decreased income.

The principal adaptation methods that were discovered in the analysis of the interviews were migration to cities, seeking alternative livelihoods, building canals and irrigation systems and intending to sow new crops. Hence, again statistics showed contradicting results, suggesting that climate change had no strong significance on migration.

The interview data suggests that educated smallholders with strong social capacity and economic assets had the strongest adaptive capacity to the climatic changes. However, the majority of the farmers were discovered not to have these capacities. For these smallholders, the support of external actors became highly important. Moreover, the results demonstrated that larger market forces and lack of political engagement in the highlands have further deepened socioeconomic struggles in the case study region.

Overall, the findings of this study indicate that climate-related changes have already had adverse implications on smallholders' vulnerability in the study site and that the farmers perceive climate change as a threat. However, in contrast to previous studies, this paper revealed that climate factors may not be as substantial in increasing vulnerability of Andean highland populations as projected and that other factors may have even more significant importance. It is, hence, suggested that behind the vulnerability of the Andean small-scale farmers lies a complex network of social, economic and political problems that climatic changes only trigger. It is recommended that the significance of the diverse variables be further examined in future vulnerability assessments and that the local policymakers consider all the multifaceted dimensions when designing adaptation strategies to climate threats.

Notes

1. The concept of a socio-ecological system (SES) implies the intertwist of nature and human subsystems that are scrutinized as solid entity in vulnerability assessments (Gallopín 2006).
2. Interpolation is a method that can be used to estimate missing values in a function or data series

(Merriam-Webster 2016). Numerous, more complex interpolation techniques are in use in mathematical analysis. In this paper, however, interpolation was done by counting arithmetic means of the closest existing values for estimation of the missing data.

[3] The 1980s was a turbulent decade in Peru's economic history. Throughout the decade, the country confronted several hyperinflations; between 1979 and 1989 the prices were rising and falling heavily due to various economic crisis and climatic disasters caused by El Niño in 1983 (Webb 1988; Cermeño & De la Cruz 1991). In this study, in order to offset the impact of the inflations, farm gate prices were converted from *nuevos soles* to U.S. dollars.

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Competing Interests
The author has no competing interests to declare.

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